THE EFFECT OF VARIOUS TREE SPECIES ON SOIL

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THE question of the effect of forest vegetation on soil formation processes has continued to attract the attention of many investigators. In the last few years the old views have been reviewed and made more realistic because of the manifold investigations of the interrelation between woody vegetation and soils (10, 5, 9, 2, 3, 1, 7, 8, 4 and others). But, as S. V. Zonn (2, 3) correctly states, there are still not enough data on the effect of different species on the physical and physicochemical properties of podzolic soils in different types of forests.

We have obtained some material on the effect of planting individual species of trees on the physical and physicochemical properties of different soils in young pine-oak plantations (V_2), young mixed stand (S_2) and young oak stand (D_2). The work was carried out at the Forest Institute, Academy of Sciences, Ukrainian SSR from 1951 to 1956, inclusive, on pure plantations of Scotch pine, European white birch, spruce, *Larix decidua*, English oak and a series of mixed coniferous-broad-leaved and broad-leaved plantations 40 to 60 years old (in the Kiyev, Volynsk and Khmelnits regions, Ukrainian SSR). In 1955, supplementary investigations were made of sixteen pure plantings of six-year-old species of trees: English oak, red oak, mountain oak, European white birch, hornbeam, black locust, honey locust, *Tilia cordata* Mill., Norway and silver maple, wild pear and western beech at the Goloseyev Scientific Experimental Base, Forest Institute, Academy of Sciences, Ukrainian SSR.

Within each forest type the plantings investigated grow on one or more different soils—young pine-oak plantations on sod slightly-podzolic clay sandy soils and sod slightly-podzolic gley sandy soils, and young mixed stand on sod-podzolic loamy sand soils, sod medium-podzolic sandy loam soils and thick, low-humus, leached silt loam chernozem.

The investigations were carried out according to the following method. In each forest type on uniform soils, pure and mixed plantings of the species previously listed were selected on an area totalling 1.5 to 15 hectares. In each planting a test area was laid out of 0.25 to 0.5 hectares, along with the others, for the soil investigations. Detailed descriptions were made of the morphological soil characteristics, the woody vegetation and the geomorphology. Soil samples for analysis were taken from depths of 0 to 10, 10 to 20, 30 to 40, 50 to 60, 70 to 80 and 100 to 110 cm. In a few cases samples were taken from a depth of 180 cm.

The following soil properties were determined: bulk density under field conditions, using a 1000 $cm.^3$ steel cylinder; specific gravity of the solid phase, pycnometrically; pore space; hygroscopic coefficient (by A. N. Nikolayev's method); water infiltration under field conditions (by P. S. Pogrebnyak's method).

Of the physicochemical indices of soil fertility, the following were determined: the pH of water and salt extracts (electrometrically); the hydrolytic acidity and total adsorbed cations (Kapen's method); adsorption capacity; degree of cation saturation; humus content (I. V. Tyurin's method); water-soluble humus (Kubelya-Timan's method); water-soluble calcium and magnesium (with Trilon B); total nitrogen (Kjeldahl's method); phosphorus (Neiman's method).

Simultaneously, studies were made of the amount of litter in the plantations, its decomposition rate and the nitrogen and phosphorus content in the litter components.

Effect of Plantations on the Physical Soil Properties

The data in Table 1 show that the physical soil properties are affected by the tree species and by the duration of their action on the soil. The effect of plantations of some species on the physical soil properties in all forest types develops most clearly in the top 10 cm. layer. Thus, the bulk volume of the soil under pure pine plantations is 1.49; where birch is predominant it is 1.35; oak, 1.30; a mixture in which oak is dominant (7 oak, 2 pine, 1 birch), 1.17. The water intake rate at the same depth (in mm. per hour) is: under birch, 101; under oak, 127; under a pine-oak-birch plantation,

TABLE 1

Effect of plantations of differing composition on some physical soil properties

Composition and age of plantation	Bulk volume			Particle density			Total pore space		
	0–10	10–20	30–40	0–10	10–20	30–40	0–10	10–20	30–40
Sod slightly-podzolic gley soil, forest type V_2									
10 pine (thinned stand) 8 years old	1.54	1.57	1.70	2.62	2.65	2.66	41.2	40.7	36.0
10 pine (dense stand) 8 years old	1.48	1.54	1.51	2.63	2.64	2.65	43.7	41.6	43.0
10 pine, 45 years old	1.39	1.58	1.44	2.60	2.62	2.62	46.5	39.6	45.0
Sod slightly-podzolic clay sandy soil, forest type V_2									
10 pine, 30 years old	1.49	1.59	1.64	2.60	2.62	2.63	42.6	39.3	37.6
5 birch, 3 oak, 2 pine, 30 years old	1.35	1.46	1.60	2.59	2.62	2.65	47.9	44.3	44.5
10 oak, 35 years old	1.30	1.50	1.48	2.57	2.62	2.63	49.4	42.7	43.7
7 oak, 2 pine, 1 birch, 40 years old	1.17	1.46	1.54	2.57	2.64	2.62	54.5	44.7	41.2
Leached low-humus chernozem, forest type D_2									
10 pine, 100 years old	1.04	1.19	1.18	2.48	2.58	2.59	58.0	53.8	54.4
10 birch, 80 years old	0.91	1.07	1.10	2.45	2.49	2.56	62.9	57.0	57.0
10 oak, 100 years old	0.92	1.11	1.16	2.50	2.53	2.57	63.2	56.1	54.9
Field	1.16	1.29	1.17	2.52	2.52	2.54	55.7	47.6	51.9

432; and under pure pine, 329. Broadleaf species (birch and oak) are able to decrease the water intake rate in the upper soil layers. This should be considered a favorable effect on coarse-textured sod slightly-podzolic soils. Pure pine plantations also decrease the water intake rate of the upper layers of sod slightly-podzolic gley sandy soils in comparison to non-forested tracts (fields, 528 mm. per hour; an eight-year-old dense pine plantation, 194; a 45-year-old natural pine plantation, 167).

In the young pine-oak plantation, no direct relation was established on sod slightly-podzolic gley sandy and clay sandy soils between the water intake rate and the pore space, especially the macro pore space; such a relation is very characteristic of young mixed stand and young oak stand on sod medium-podzolic sandy loams or thick low-humus leached chernozem. We have little data to explain the absence of such a relation. We can suggest that tree vegetation on coarse-textured soils, with the help of its root system and leaf litter, accumulates in the upper soil layer those elements which permit the synthesis of secondary minerals (including clay minerals) and organic matter which cause an increase in the water-retaining capacity and a decrease in the soil's water rate. To confirm this we may cite the increasing hygroscopic coefficient of the top 10 cm. soil layer beginning with that of non-forested tracts (0.86 milligrams percent) and passing through pure pine (0.91 to 1.52), oak and birch (1.74 to 4.83) to mixed broadleaf-coniferous plantations (2.07 to 5.12).

The effect of planting individual tree species on the physicochemical indices of soil fertility in young pine-oak plantations and mixed stand develops conspicuously. The indices of the favorable effects of tree species increase in the same order (Table 2) as in respect to the physical properties of soils (Table 1). The humus content in the upper 10 cm. layer of the soil increases under mixed pine-oak-birch plantings in the V_2 forest type to 1.82%, the total of adsorbed cations increases correspondingly from 0.75 to 3.93 milliequivalents per 100 grams of soil and the degree of cation saturation from 17 to 67%.

In the young mixed forest type the effect of

TABLE 2

Effect of pure and mixed plantations on the physicochemical indices of soil fertilitity

Composition of plantation	Age, years	Humus, percent			pH of water extract			Degree of cation saturation of soil, meq./100 g. of soil		
		0–10	10–20	30–40	0–10	10–20	30–40	0–10	10–20	30–40
Sod slightly-podzolic clay sandy soil, forest type V_2										
10 pine	30	1.44	0.85	0.61	4.9	5.3	5.1	16.8	6.4	0.0
10 birch	25	1.66	1.02	0.44	5.3	5.5	5.6	37.6	17.6	0.0
5 pine, 3 oak, 2 birch	60	1.82	0.74	0.77	6.1	6.1	5.0	66.7	46.1	0.0
Sod medium-podzolic sandy loam soil, forest type S_2										
10 larch	60	1.84	0.92	0.46	5.2	5.2	5.7	42.7	41.2	68.3
10 pine	60	2.20	1.09	0.68	5.5	5.2	5.6	57.0	50.0	82.0
10 spruce	60	2.91	1.75	0.60	5.2	4.9	6.1	44.7	27.4	72.4
4 larch, 4 oak, 2 spruce	60	4.11	1.25	0.92	5.7	5.5	5.1	72.6	67.4	58.8
Field		1.58	1.42	0.58	6.0	5.7	5.8	63.1	59.0	72.0
Thick, low-humus leached chernozem, forest type D_2										
10 larch	60	7.04	4.95	3.44	5.8	5.8	5.8	76.8	76.9	74.2
10 oak	50	7.36	5.29	4.43	5.8	5.8	5.5	79.1	76.5	70.6
Field		4.34	4.59	4.18	5.8	5.9	6.2	77.6	79.5	87.9

the plantings on the soil depends equally on the tree species and on the kind of soil. The humus content of the upper 10 cm. layer of a sod medium-podzolic sandy loam soil under larch is 1.84; under pine, 2.20; under spruce, 2.91; in a field, 1.58%. On a finer-textured soil (thick, low-humus leached chernozem) the effect of different species develops even more strongly. The percentage of humus in the soil of a field was 4.34; under larch, 7.04, under oak, 7.36: that is, the humus content in the upper soil layer almost doubled under plantings of larch and oak.

Mixed young pine-oak plantings and young mixed stand exert an especially favorable effect on soil fertility.

It is characteristic that artificial and natural plantations of different tree species develop an ameliorative effect on the soil only from the moment when their crowns join (become continuous) and they form litter. Evidence for this is the data from investigations of the sixteen species of trees planted in a checkerboard pattern. If these species are listed in order of decreasing effect on sod-podzolic loamy sand, the following series is obtained: ordinary ash, silver maple, European spruce, wild pear, honey locust, hornbeam, black locust, mountain oak, *Tilia cordata*, English oak, western beech, Norway maple, European white birch, red oak, Banks' pine and Scotch pine.

The effect of some tree species on soils of different forest types is closely related to the rate of the biological cycle of nutrients. The rate of the cycle in each of the plantations can be judged by the accumulation and decomposition of the forest litter, consisting mostly of leaves or needles (75 to 90%) which contain valuable supplies of nutrients. Nitrogen and phosphorus are the most important (Table 3).

TABLE 3

Effect of pure and mixed plantings on the supply of litter containing ash, phosphorus and nitrogen, kilograms per hectare, of forest type V_2

Elements	Composition of planting					
	10 pine	10 birch	10 oak	7 oak 2 pine 1 birch	5 birch 3 oak 2 pine	5 pine 3 oak 2 birch
Litter	25,333[a]	12,878[a]	11,933	11,856	14,158	24,232[a]
Ash	3,796[a]	1,892[a]	1,442	1,493	1,521	4,724[a]
P_2O_5	48.1	35.0	30.6	27.1	32.6	53.3
Nitrogen	315.4	239.9	177.3	165.4	224.7	343.5

[a] According to data from A. K. Kovalevskiy.

TABLE 4

Effect of pure and mixed plantings on the nitrogen content of a sod slightly-podzolic clay sandy soil, metric tons per hectare, of type V_2 forest

Composition	Soil layers, centimeters				
	0–3	3–10	10–20	20–40	Total 0–40
10 pine	0.41	0.71	0.40	0.80	2.32
10 oak	0.69	0.56	0.62	0.66	2.53
10 birch	0.59	0.61	0.80	1.04	3.04
7 oak, 2 pine, 1 birch	0.60	0.66	0.60	0.80	2.66
5 birch, 3 oak, 2 pine	0.41	0.75	0.85	0.67	2.68
5 pine, 3 oak, 2 birch	1.07	1.09	0.65	0.80	3.61

From the data of Table 3 we conclude that the litter of pure plantings of pine (or of mixed coniferous-broad-leaved species in which pine is predominant) retain 60 to 100% more phosphorus and nitrogen than does the litter of pure broad-leaved plantings (birch, oak) or of mixed coniferous-broad-leaved plantings with predominance of broad-leaved types. Plantings of pure broad-leaved species, or of mixtures in which they predominate, liberate phosphorus and nitrogen from the litter half again to twice as rapidly, and by this means accelerate the cycle of these valuable nutrient elements between the plants and the soil, continuously re-establishing and supplementing the nutrient supply.

According to Table 4, the soil's nitrogen content clearly shows the effect on it of certain species. The broad-leaved species (birch and oak) which enter into the composition of the coniferous plantings in the pine-oak plantations are very important in soil improvement.

The liberation of nutrients from the litter, their use by plants and their intake into the soil are irregular during the growing period (Figs. 1, 2 and 3). The litter of pure broad-leaved and mixed coniferous-broad-leaved plantings is notable for its high content of nitrogen and phosphorus during the entire growing season, with characteristic maxima and minima. The maximum nitrogen content of the litter is in June and September; that of phosphorus is in September and November. The quantity of nitrogen in the soil under the same plantings is expressed by an M-shaped curve with characteristic minima in June and September, just when the nitrogen content of the litter reaches its maxima.

A similar pattern of the content of soil nutrients was observed in the soils of the Tellermanov Experimental Forestry District by A. F. Tyulin and K. G. Shcherbina (11).

We agree with A. M. Zrazhevskiy, who says that loss of nitrogen from the upper soil layers during the summer months is related to the dynamics of the mesofauna. The minimum soil nitrogen content (which is maximum in the litter) is observed during the driest period—from July to September—when the mesofauna leaves the litter and the upper soil layer and departs to deeper layers. Evidently the decrease in nitrogen content at this time takes place because of its accumulation in protein form in the bodies of organisms.

Conclusions

1. The effect of plantations of some tree species on the physical and physicochemical soil properties in young pine-oak stands and young mixed-stand is clearly differentiated. The effect is determined by the tree species and the soil type.

2. In the pine-oak type of forest, the physical soil properties change under plantings of individual species, just as they do in the mixed stand and oak stands (except for the permeability), but the absolute values of these parameters in pine-oak plantings change considerably less than in oak groves.

3. In pine-oak plantations and in mixed-stand, the favorable effect of the plantings on the physicochemical soil properties increases in a series beginning with pure pine, larch and spruce stands, followed by pure broad-leaved stands and then by mixing coniferous-broad-leaved plantings of differing composition.

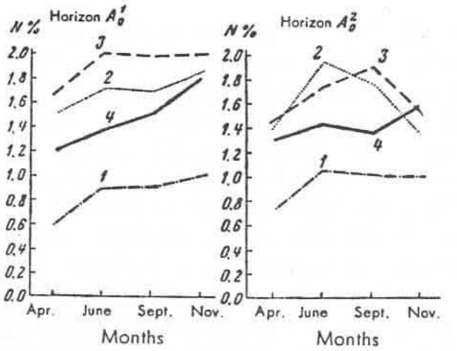

FIG. 1.—Effect of plantings of different compositions on the total nitrogen content of the litter. Plantings: 1—pure pine; 2—pure oak; 3—pure birch; 4—mixed pine-oak-birch.

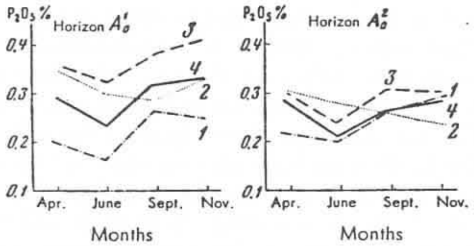

FIG. 2.—The effect of plantings of different compositions on the phosphorus content of the litter. (Symbols as in Fig. 1)

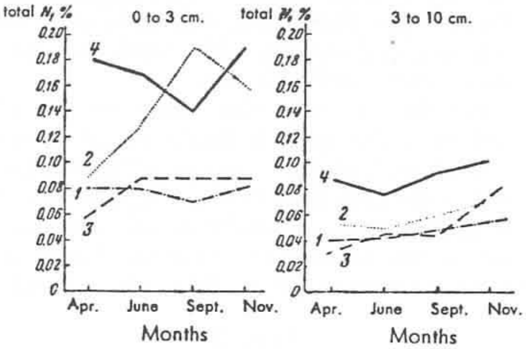

FIG. 3.—Effect of plantings of different compositions on the total nitrogen content of a sod-podzolic clay-sandy soil. (Symbols as in Fig. 1)

4. The favorable effect of the plantings of individual tree species grows stronger with age and density of the canopies. The earlier the tree crowns touch each other, the more quickly they form forest litter, root litter, and so forth. Individual types of trees in young mixed stand (6 to 8 years old) form the following ascending series with respect to a favorable effect on the soils: Banks' pine, red oak, Scotch pine, spruce and *Larix decidua*, European white birch, Norway and silver maple, western beech, English oak and mountain oak, *Tilia cordata*, black locust, honey locust, wild pear and taller ash.

5. Within each forest type, the favorable effect of individual tree species develops more clearly and extensively as the soil on which they grow has finer texture.

6. The conclusions of P. S. Pogrebnyak (5) and S. V. Zonn (3) regarding the soil-improving role of oak and birch in forests of the pine-oak type have been confirmed, as have N. P. Remezov's conclusions regarding the increase in rate of the biological cycle in proportion to the extent of participation of broad-leaved species in coniferous plantations.

7. We have shown specific dynamic characteristics of the nitrogen and phosphorus in the litter and of the soil nitrogen under pure plantings of pine, birch, oak and mixed coniferous-broad-leaved plantings on sod slightly-podzolic clay sandy soils. The data obtained correspond to the regular patterns established by A. F. Tyulin and K. G. Shcherbina (11) in studying oak plantations in the Tellermanov Forestry District.

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